

# Neutrino Mass Matrix in the Minimal Supergravity Model: Bi-large Mixing with Trilinear R-parity Violation \*

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We study the correlation between the neutrino oscillation and the production/decay of the lightest supersymmetric particle(LSP) in the context of the minimal supergravity model(mSUGRA) without R-parity. We show how the neutrino masses and mixing which are consistent with the recent neutrino data can be obtained in this model, and describe how to probe the model by observing the LSP decay at collider experiments. It is shown that the generic 1-loop contributions to neutrino masses are too small to account for the solar and atmospheric neutrino oscillations and thus some fine cancellation in tree-level contribution is required to severely constrain the viable parameter space. In most parameter space of mSUGRA, the neutralino or the stau is LSP. Examining both cases, we find that there is a simple correlation between the neutrino mixing angles and the LSP branching ratios in the small  $\tan\beta$  region so that the model can be clearly tested in the future colliders. In the large  $\tan\beta$  region, such a correlation is obscured by the large tau Yukawa contribution which makes it nontrivial to test the model.

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## I. INTRODUCTION

The recent progresses in neutrino experiments has led us to convince the existence of neutrino masses and flavor mixing. [1]. In this regard, of primary interest are to look for New Physics candidates which are inherited not only with a natural mechanism to generate the observed neutrino mass matrix and but also with some other predictions that can be tested in the near future. One of the best-motivated models endowing such a property would be the Minimal Supersymmetric Standard Model (MSSM) with lepton number violation via R-parity breaking terms [4][5][6], as such models may produce lepton flavour violating signals predicted by the observed neutrino mixing and thus can be tested in future collider experiments [2][3]. The particle spectrum in MSSM depends on the supersymmetry breaking mechanism. One of the most popular scenarios for supersymmetry breaking is the minimal supergravity scenario (mSUGRA) [7], which assumes a universal gaugino mass  $M_{1/2}$ , a universal scalar mass  $m_0$ , a universal trilinear coupling  $A_0$  and  $B_0$  at  $M_{GUT}$  scale. This framework can successfully evade the appearance of dangerous flavor changing neutral current(FCNC) and is highly predictive because there exist only 5 independent parameters in the model. In this work, we do complete phenomenological analysis on the masses and mixing of neutrinos and lepton number violating signature of LSP decays in the con-

text of mSUGRA with trilinear R-parity violation. The neutrino mass matrix is calculated up to the one-loop order, and it is studied how the predictions concerned with neutrino parameters in mSUGRA can be probed from the collider signals. In almost all parameter space of mSUGRA, the LSP is predicted to be a neutralino or a stau. In both cases, we calculate the production cross section, decay rate, and branching ratios of the LSP to investigate the correlations between neutrino oscillation parameters and collider signatures from the various channels of LSP decay.

## II. NEUTRINO MASS MATRIX AND FLAVOR STRUCTURE OF TRILINEAR COUPLINGS IN MSUGRA

Let us begin by writing the superpotential in the basis where the bilinear term  $L_i H_2$  is rotated away :

$$W_0 = \mu H_1 H_2 + h_i^e L_i H_1 E_i^c + h_i^d Q_i H_1 D_i^c + h_i^u Q_i H_1 U_i^c \quad (1)$$

$$W = \lambda_i L_i L_3 E_3^c + \lambda'_i L_i Q_3 D_3^c, \quad (2)$$

where  $W_0$  is R-parity conserving part, whereas  $W$  is R-parity violating part, and we assume the dominance of  $\lambda'_i \equiv \lambda'_{i33}$  and  $\lambda_i \equiv \lambda_{i33}$  ( $i = 1, 2, 3$ ) over the other trilinear couplings of lower generations and the universality at the GUT scale is imposed. In this framework, there are 10 free parameters of the model, i.e. five conventional ones plus five R-parity violating ones;

$$m_0, A_0, M_{1/2}, t\beta, \text{sign}(\mu) ; \lambda'_{1,2,3}, \lambda_{1,2}$$

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where  $t_\beta = \tan\beta$  is the ratio of two Higgs VEVs. As is well known, non-universality is developed at the weak scale via RGE evolution. The RGE in this basis can be found in Ref. [8]. Non-vanishing soft terms are given by

$$V = m_{L_i H_1}^2 L_i H_1^\dagger + B_i L_i H_2 + + B H_1 H_2 + h.c. \quad (3)$$

where  $B_i$  is the dimension-two soft parameter. We note that non-trivial VEVs for sneutrinos can be generated in this case. Including 1-loop contributions  $V_{loop}$ , we obtain the following relation which comes from the minimization condition for the scalar potential,

$$\xi_i = \frac{m_{L_i H_1}^2 + B_i t_\beta + \Sigma_{L_i}^{(1)}}{m_{\tilde{\nu}_i}^2 + \Sigma_{L_i}^{(2)}}, \quad (4)$$

where  $\xi_i \equiv \langle \tilde{\nu}_i \rangle / \langle H_1^0 \rangle$ , and  $\Sigma_{L_i}^{(1,2)}$  are 1-loop contributions generated from  $V_{loop}$ . The explicit forms of  $\Sigma_{L_i}^{(1,2)}$  are presented in Ref. [8],[9]. Introducing another variables,

$$\eta_i \equiv \xi_i - \frac{B_i}{B}, \quad (5)$$

we can obtain the relation,

$$\frac{\xi_i - \eta_i}{\xi_i} = -\frac{m_{\tilde{\nu}_i}^2}{m_A^2 s_\beta^2} \frac{1}{1 + \frac{m_{L_i H_1}^2}{B_i t_\beta}}, \quad (6)$$

whose non-zero values are due to the neutral scalar loops. Then, the tree-level mass is presented in terms of  $\xi_i$ ;

$$M_{ij}^{tree} = -\frac{M_Z^2}{F_N} \xi_i \xi_j c_\beta^2 \quad (7)$$

where  $F_N = M_1 M_2 / (c_W^2 M_1 + s_W^2 M_2) + M_Z^2 c_{2\beta} / \mu$ . Including 1-loop corrections, the neutrino mass matrix is written as

$$M_{ij}^\nu = -\frac{M_Z^2}{F_N} \xi_i \xi_j \cos^2 \beta - \frac{M_Z^2}{F_N} (\xi_i \delta_j + \delta_i \xi_j) \cos \beta + \Pi_{ij}, \quad (8)$$

where  $\Pi_{ij}$  denotes the 1-loop contribution of the neutrino self energy, and

$$\begin{aligned} \delta_i = & \Pi_{\nu_i \tilde{B}^0} \left( \frac{-M_2 \sin^2 \theta_W}{M_{\tilde{\gamma}} M_W \tan \theta_W} \right) + \Pi_{\nu_i \tilde{W}_3} \left( \frac{M_1 \cos^2 \theta_W}{M_{\tilde{\gamma}} M_W} \right) \\ & + \Pi_{\nu_i \tilde{H}_1^0} \left( \frac{\sin \beta}{\mu} \right) + \Pi_{\nu_i \tilde{H}_2^0} \left( \frac{-\cos \beta}{\mu} \right), \end{aligned} \quad (9)$$

$$M_{\tilde{\gamma}} = c_W^2 M_1 + s_W^2 M_2. \quad (10)$$

Exact expressions of the 1-loop contributions  $\Pi$ 's are presented in Ref. [9]. We note that the conventional tau-stau, bottom-sbottom loops and neutral scalar (sneutrino/neutral Higgs boson) loops are essential to achieve

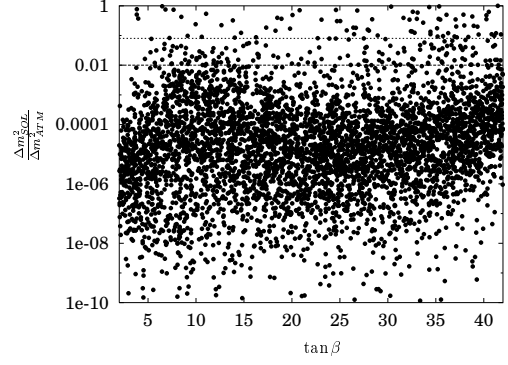


FIG. 1: Plots  $\tan\beta$  vs. mass square ratio for general points, the region between the two straight lines is the allowed one by neutrino data

a realistic neutrino mass matrix for  $\tan\beta \lesssim 30$ , and they are given by

$$\begin{aligned} M_{ij}^{loop} = & 3 \frac{\lambda'_i \lambda'_j}{8\pi^2} \frac{m_b^2 (A_b + \mu \tan\beta)}{m_{b_1}^2 - m_{b_2}^2} \ln \frac{m_{b_1}^2}{m_{b_2}^2} \\ & + \frac{\lambda_i \lambda_j}{8\pi^2} \frac{m_\tau^2 (A_\tau + \mu \tan\beta)}{m_{\tau_1}^2 - m_{\tau_2}^2} \ln \frac{m_{\tau_1}^2}{m_{\tau_2}^2}. \end{aligned} \quad (11)$$

It is found that the charged scalar (slepton/charged Higgs boson) loops are important only for  $\tan\beta > 30$  as observed in Ref. [10], whereas the neutral scalar loops are important for all  $\tan\beta$  in our case. We have observed that the tree level masses are much larger than the 1-loop contributions in mSUGRA, which makes it difficult to accommodate the solar and atmospheric neutrino oscillations. Thus, we need some cancellation in  $\xi_i$  so that the tree mass becomes comparable to the 1-loop contributions. Then, we can obtain a desirable neutrino mass matrix the by combining the tree and 1-loop masses appropriately, but it is possible in some fine-tuned parameter space, as will be shown later. In this case, however, we lose nice predictability of atmospheric and solar neutrino mixing angles measurable in colliders.

### III. NUMERICAL RESULTS: FITTING THE NEUTRINO DATA

First of all, we obtain the parameter sets consistent with the solar and atmospheric neutrino data by scanning the input parameters within the ranges,

$$100\text{GeV} \leq m_0 \leq 1000\text{GeV}, \quad (12)$$

$$100\text{GeV} \leq M_{1/2} \leq 1000\text{GeV}, \quad (13)$$

$$0\text{GeV} \leq A_0 \leq 700\text{GeV}, \quad (14)$$

$$2 \leq \tan\beta \leq 43. \quad (15)$$

The ranges for  $R$ -parity violating parameters we scan are given

$$4 \times 10^{-6} \leq |\lambda_1| \leq 6 \times 10^{-4}, \quad (16)$$

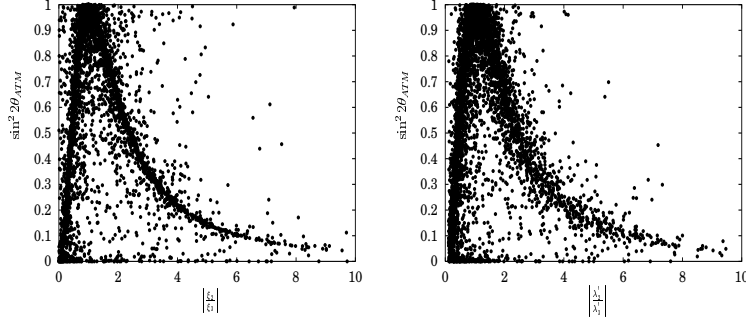


FIG. 2: Atmospheric neutrino mixing angle vs.  $|\xi_3/\xi_3|$  and  $|\lambda'_2/\lambda'_3|$  for general points

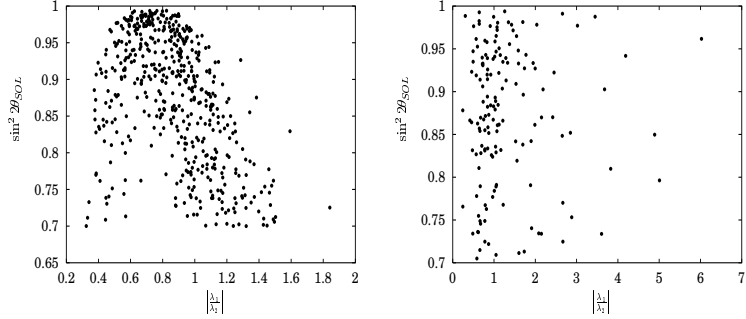


FIG. 3: The solar mixing angle and  $\lambda_1/\lambda_2$  ratio for solution points, Left : small  $\tan \beta$ ,  $\sim 3 - 15$  Right : for large  $\tan \beta$ ,  $\sim 30 - 40$

$$4 \times 10^{-6} \leq |\lambda_2| \leq 6 \times 10^{-4}, \quad (17)$$

$$3 \times 10^{-9} \leq |\lambda'_1| \leq 10^{-4}, \quad (18)$$

$$4 \times 10^{-6} \leq |\lambda'_2| \leq 10^{-3}, \quad (19)$$

$$4 \times 10^{-6} \leq |\lambda'_3| \leq 10^{-3}. \quad (20)$$

We set the signs of  $M_{1/2}$  and  $A_0$  arbitrary, but find that most of the allowed parameter space corresponds to the case that both signs are positive. We also find that there are strong correlations between atmospheric neutrino mixing angle and  $\lambda'_i$ 's. In order to account for the large atmospheric angle and small Chooz angle, we should take  $\lambda'_1 \ll \lambda'_2 \approx \lambda'_3$ . We have confirmed this by numerical calculations. In mSUGRA scenario, the tree level value of neutrino mass is much larger the 1-loop contributions in general, whereas the allowed parameter sets from the neutrino data are not tree-dominant at all. So we should make the tree mass terms comparable to the 1-loop contributions, and it can be possible in the case that some cancellation in  $xi_i$  occurs. In doing so, however, we lose beautiful predictability of atmospheric and solar neutrino mixing angles measurable in colliders. FIG.1 shows scattered plot of the ratio  $\Delta m_{sol}^2/\Delta m_{atm}^2$  vs.  $\tan \beta$  in the randomly generated parameter space. The points in the region between the two dotted lines give the right value of the mass square ratio. Only small set of scattered points lie in that region. We find that

only small number of points among them are consistent with bi-large mixing.

We note that the relative sizes of R-parity violating parameters are correlated with neutrino mixing pattern. But due to the cancellation in  $xi_i$ , it turns out that such a correlation is rather weak. In FIG. 2, we see some correlations between the atmospheric neutrino mixing angle and  $\xi_2/\xi_3$ ,  $\lambda'_2/\lambda'_3$  for general parameter sets although they are not very strong because many data points do not lead to tree-dominant neutrino masses. Even though the correlations look so weak, we can obtain some constraints on  $|\lambda'_2/\lambda'_3|$  from the neutrino data  $0.4 \lesssim |\lambda'_2/\lambda'_3| \lesssim 2.5$  for small  $\tan \beta$  and  $0.3 \lesssim |\lambda'_2/\lambda'_3| \lesssim 3.3$  for large  $\tan \beta$ . In FIG. 3, we plot the solar mixing angle vs.  $\lambda_1/\lambda_2$  ratios for small  $\tan \beta$  and large  $\tan \beta$  cases, respectively. We see that there are strong correlations between the solar mixing angle and  $\lambda_1/\lambda_2$  ratios. Similar to the above case, we can get some constraints  $0.3 \lesssim |\lambda_2/\lambda_3| \lesssim 1.6$  for small  $\tan \beta$  and  $0.2 \lesssim |\lambda_2/\lambda_3| \lesssim 5$  for large  $\tan \beta$ . Collecting these constraints, the solutions are found for the ranges of

$$\lambda_{1,2}, \lambda'_{2,3} = (0.1 - 2) \times 10^{-4}, \quad (21)$$

$$\lambda'_1 < 2.5 \times 10^{-5}. \quad (22)$$

Let's summarize the results of this section. In general, in large portion of parameter space, the tree level contribution is much larger than those from 1-loop, so it is hard to get the right mass square ratio which is about

$\mathcal{O}(10^{-2})$ . The solutions are possible by suppressing the tree level contributions, which arises through the cancellation in  $\xi_i$ . In this case, the correlations between  $\xi_i$  and mixing angles become worse. In addition to the important 1 loop correction by stau and sbottom, the neutral scalar loop can give the important contribution to the neutrino masses, through the deviation of  $\eta_i$  from the direction of  $\xi_i$ , which determine the tree level neutrino mass matrix. Instead of those, there are stronger correlations between the atmospheric mixing angle and  $\lambda'_2/\lambda'_3$ , the solar mixing angle and  $\lambda_1/\lambda_2$ . For small  $\tan\beta$ , it is possible to probe these in collider signal. It will be shown in the next section.

#### IV. COLLIDER SIGNALS OF THE MODEL

It is expected that the luminosity of the next linear collider can reach the  $1000\text{fb}^{-1}/\text{yr}$ , and the center of mass energy over 1 TeV[11][12]. With such a capacity of the linear collider, it could be possible to prove the supersymmetric particles pair produced[13] as well as the decay of LSP inside the detector[14]. We present here the total cross section and decay rate for various parameter sets, and discuss the possibility to probe the structure of R-parity violating parameters constrained by neutrino data. In the previous sections we got the parameter sets which are consistent with the known neutrino data. Those results suffice to determine which is the LSP, neutralino or light stau. In TABLE I-III, we present the results of decay rate and branching ratios. The TABLE I shows the results for the stau LSP case with small  $\tan\beta$ . TABLE II and III correspond to the Neutralino LSP cases for small  $\tan\beta$ . The former is the case that only 3-body decay is permitted, whereas the latter is the case that both 2-body and 3-body decays are permitted. Since the decay lengths are smaller than a few  $cm$  for all cases, it is possible to detect their decay modes in the next linear collider.

First of all, let's discuss the stau LSP cases. For small  $\tan\beta$ ,  $\tilde{\tau}_1 \sim \tilde{\tau}_R$  due to the small off-diagonal part. Then the light stau almost decays into leptons via  $\lambda_i L_i L_3 E_3^c$  terms in the superpotential. In this case, the following relation holds,

$$\begin{aligned} Br(e\nu) : Br(\mu\nu) : Br(\tau\nu) \\ \simeq |\lambda_1|^2 : |\lambda_2|^2 : |\lambda_1|^2 + |\lambda_2|^2. \end{aligned} \quad (23)$$

Thus, by observing the lepton branching ratios, one can measure the ratio of  $\lambda_1$  and  $\lambda_2$ . If this value is out of the range constrained by neutrino data, given in the last section, we can exclude this model. If  $\tan\beta$  become larger, the above relation does not hold any more because the Yukawa coupling plays an important role in this case. In other words,  $\tilde{\tau}_1$  cannot be considered as almost  $\tilde{\tau}_R$ , but should be the combination of  $\tilde{\tau}_L$  and  $\tilde{\tau}_R$  and then the couplings are given by the mixture of  $\lambda_i$  and  $h_\tau$ .

Next, let's consider the neutralino LSP cases. The 2-

body decay rates are proportional to  $|\xi_i|^2$ ,

$$\Gamma(\nu_i Z) \propto |\xi_i|^2, \quad (24)$$

$$\Gamma(l_i W) \propto |\xi_i|^2. \quad (25)$$

For 3-body decay modes, the lepton-quark-quark branching ratios are proportional to  $|\xi_i|^2$  since  $W$  boson exchange diagrams are dominant. So we can have the following relation,

$$Br(ejj) : Br(\mu jj) : Br(\tau jj) = |\xi_1|^2 : |\xi_2|^2 : |\xi_3|^2. \quad (26)$$

Thus, we can obtain the information of  $\xi_i$  ratio by measuring the branching ratios, but it is difficult to test mSUGRA scenario for massive neutrinos via collider signals because the correlation between  $\xi_i$ 's and neutrino oscillation parameters is diminished as pointed out in the last section. Similar to the stau LSP case, for small  $\tan\beta$ ,  $\nu l_i^\pm \tau^\mp$  branching ratios provide  $\lambda_i$  information on them;

$$\begin{aligned} Br(\nu e^\pm \tau^\mp) : Br(\nu \mu^\pm \tau^\mp) : Br(\nu \tau^\pm \tau^\mp) \\ \simeq |\lambda_1|^2 : |\lambda_2|^2 : |\lambda_1|^2 + |\lambda_2|^2 \end{aligned} \quad (27)$$

Likewise, if we measure the above branching ratios, the models can be tested by comparing them with the range allowed by neutrino data. But since, for large  $\tan\beta$ , the terms generated from  $h_\tau L_3 H_1 E_3^c$  in the superpotential become large, and thus the above relation (27) breaks, it is impossible to test this scenario. The examples are presented in the TABLE II and III. In addition, we note that  $\eta_i$ 's are rather big in all cases, which implies that some cancellations in  $\xi_i$ 's occur, as expected before.

#### V. CONCLUSION

Based on the recent precise experimental results for neutrino oscillations, we have studied the minimal supergravity model with the lepton number violation via R-parity violating terms [4]. Since it is impossible to account for large mixing angle solution of solar neutrino problem in mSUGRA with only bilinear R-parity violations, we should include the general trilinear R-parity violations. So there are additional 5 parameters  $\lambda_i$  and  $\lambda'_i$  besides the 5 parameters which are from the ordinary minimal supergravity model. In future collider which can reach its CM energy over 1 TeV and luminosity up to  $1000\text{fb}^{-1}$  in a year[11][12], we expect that it is possible to probe mSUGRA without R-parity via the LSP decay. We have presented how neutrino mass matrix from mSUGRA with R-parity violation can be constructed at the 1-loop level. From our analysis, we found that most parameter space which is consistent with neutrino data leads to 1-loop contributions as large as comparable with tree level masses. We have found the strong correlation between solar neutrino mixing angle and  $\lambda_1/\lambda_2$ , and also between atmospheric neutrino mixing angle and  $\lambda'_2/\lambda'_3$ . For searching the LSP decays, we have considered two cases in mSUGRA, neutralino LSP and scalar tau LSP,

	set A : Stau LSP		
	$\tan \beta = 5.15$	$\text{sgn}(\mu) = -1$	$\mu = -801.23 \text{ GeV}$
	$A_0 = 39.47 \text{ GeV}$	$m_0 = 105.02 \text{ GeV}$	$M_{1/2} = 671.02 \text{ GeV}$
$\tilde{\lambda}'_i$	$8.403 \times 10^{-6}$	$-7.663 \times 10^{-5}$	$-6.792 \times 10^{-5}$
$\tilde{\lambda}_i$	$8.739 \times 10^{-5}$	$-7.444 \times 10^{-5}$	0
$\xi_i^0$	$-1.003 \times 10^{-6}$	$-3.642 \times 10^{-6}$	$-4.401 \times 10^{-6}$
$\xi_i$	$-9.897 \times 10^{-7}$	$-3.045 \times 10^{-6}$	$-3.728 \times 10^{-6}$
$\eta_i$	$1.011 \times 10^{-6}$	$-1.313 \times 10^{-5}$	$-1.192 \times 10^{-5}$
BR	$e$	$\mu$	$\tau$
$l_i \nu$	28.93 %	20.99 %	50.02 %
$\bar{t} b$		$\sim 0.066 \%$	
	$m_{\tilde{\tau}_1} = 278.59 \text{ GeV}$	$\Gamma = 2.921 \times 10^{-7} \text{ GeV}$	
	$\sigma_{e^+e^- \rightarrow \tilde{\tau}_1 \tilde{\tau}_1^*} \simeq 1.450 \times 10^{-2} \text{ (Pb)}, \quad \sqrt{s} = 1 \text{ TeV}$		

$$(\Delta m_{31}^2, \Delta m_{21}^2) = (2.50 \times 10^{-3}, 1.13 \times 10^{-4}) \text{ eV}^2$$

$$(\sin^2 2\theta_{atm}, \sin^2 2\theta_{sol}, \sin^2 2\theta_{chooz}) = (0.98, 0.77, 0.03)$$

TABLE I: A trilinear model realizing the LMA solution for stau-LSP case. Here the couplings  $\tilde{\lambda}'_i$  and  $\tilde{\lambda}_i$  can be considered as input parameters defined at the weak scale.

	setB : Neutralino LSP		
	$\tan\beta = 4.94$	$\text{sgn}(\mu) = -1$	$\mu = -200.46 \text{ GeV}$
	$A_0 = 38.93\text{GeV}$	$m_0 = 333.66 \text{ GeV}$	$M_{1/2} = 160 \text{ GeV}$
$\tilde{\lambda}'_i$	$-9.326 \times 10^{-9}$	$-7.811 \times 10^{-5}$	$-7.560 \times 10^{-5}$
$\tilde{\lambda}_i$	$-5.628 \times 10^{-5}$	$-7.345 \times 10^{-5}$	0
$\xi_i^0$	$-1.234 \times 10^{-6}$	$3.247 \times 10^{-7}$	$1.880 \times 10^{-6}$
$\xi_i$	$-1.211 \times 10^{-6}$	$2.749 \times 10^{-7}$	$1.831 \times 10^{-6}$
$\eta_i$	$-2.007 \times 10^{-6}$	$-1.169 \times 10^{-5}$	$-8.742 \times 10^{-6}$
BR	$e$	$\mu$	$\tau$
$\nu jj$		47.01 %	
$l_i^\pm jj$	$3.88 \times 10^{-2} \%$	$2.00 \times 10^{-3} \%$	$8.87 \times 10^{-2} \%$
$\nu l_i^\pm l_3^\mp$	9.76 %	16.60 %	26.39 %
	$m_{\tilde{\chi}_1^0}=59.37 \text{ GeV}$	$\Gamma = 7.137 \times 10^{-15} \text{ GeV}$	
	$\sigma_{e^+e^-\rightarrow\tilde{\chi}_1^0\tilde{\chi}_1^0} \simeq 4.897 \times 10^{-2} \text{ (Pb)}, \quad \sqrt{s} = 1 \text{ TeV}$		

$$(\Delta m_{31}^2, \Delta m_{21}^2) = (2.51 \times 10^{-3}, 9.64 \times 10^{-5}) \text{ eV}^2$$

$$(\sin^2 2\theta_{atm}, \sin^2 2\theta_{sol}, \sin^2 2\theta_{chooz}) = (0.98, 0.99, 0.008)$$

TABLE II: Neutralino-LSP case, only 3-body decays are possible

and searched each parameter space regions by varying  $m_0$  and  $M_{1/2}$ . For our purpose, we have calculated the production cross section for each cases. For stau LSP case, 2-body decay modes are dominant. Since stau LSP is almost  $\tilde{\tau}_R$  for most parameter space, its branching ratios of the decay into top and bottom quark is negligibly small. Since stau LSP decay into  $l_i \nu$  takes place via  $\lambda_i$  couplings, it is possible to obtain the information on  $\lambda_i$ 's from branching fractions. We found that  $Br(e\nu) : Br(\mu\nu) : Br(\tau\nu) = |\lambda_1|^2 : |\lambda_2|^2 : |\lambda_1|^2 + |\lambda_2|^2$  for not too large  $\tan \beta$ . For neutralino LSP cases, similar analysis has been done. Unlike the stau LSP cases,

neutralino LSP can decay into 3-body final states as well as 2-body decay. From the branching fractions  $Br(l_i jj)$  for various decay channels of neutralino LSP, we have determined the ratios of  $\xi_i$ 's, which in turn give the desirable tree level neutrino mass matrix. But, due to rather large loop contributions to neutrino masses the predictability for neutrino parameters is diminished. For small  $\tan \beta$ , we have obtained the  $\lambda_i$ 's information which are strongly correlated with solar neutrino mixing angle from the branching fractions  $Br(\nu l_i^\pm \tau^\mp)$ . But unluckily, since Yukawa couplings become larger for large  $\tan \beta$ , it is impossible to get information on  $\lambda_i$ 's. Consequently,

	setC : Neutralino LSP		
	$\tan \beta = 4.05$	$\text{sgn}(\mu) = -1$	$\mu = -535.92 \text{ GeV}$
	$A_0 = 14.28 \text{ GeV}$	$m_0 = 113.88 \text{ GeV}$	$M_{1/2} = 444.57 \text{ GeV}$
$\tilde{\lambda}'_i$	$-9.069 \times 10^{-9}$	$-1.396 \times 10^{-4}$	$-1.842 \times 10^{-4}$
$\tilde{\lambda}_i$	$-7.966 \times 10^{-5}$	$-7.995 \times 10^{-5}$	0
$\xi_i^0$	$1.274 \times 10^{-6}$	$2.896 \times 10^{-6}$	$2.138 \times 10^{-6}$
$\xi_i$	$1.212 \times 10^{-6}$	$2.976 \times 10^{-6}$	$2.409 \times 10^{-6}$
$\eta_i$	$4.038 \times 10^{-7}$	$-1.305 \times 10^{-5}$	$-1.768 \times 10^{-5}$
BR	$e$	$\mu$	$\tau$
$\nu jj$		14.77%	
$l_i^\pm jj$	$6.36 \times 10^{-2} \%$	$3.84 \times 10^{-1} \%$	$2.51 \times 10^{-1} \%$
$\nu l_i^\pm l_3^\mp$	20.96 %	21.186 %	42.09 %
	$m_{\tilde{\chi}_1^0} = 195.00 \text{ GeV}$	$\Gamma = 4.744 \times 10^{-11} \text{ GeV}$	
	$\sigma_{e^+e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0}$	$\simeq 0.197 \text{ (Pb)},$	$\sqrt{s} = 1 \text{ TeV}$

$$(\Delta m_{31}^2, \Delta m_{21}^2) = (2.50 \times 10^{-3}, 6.81 \times 10^{-5}) \text{ eV}^2$$

$$(\sin^2 2\theta_{atm}, \sin^2 2\theta_{sol}, \sin^2 2\theta_{chooz}) = (0.95, 0.96, 0.007)$$

TABLE III: Neutralino-LSP case, both 2- and 3-body decays are possible.

for both stau LSP and neutralino LSP, it is possible to probe the relations between neutrino oscillation and R-parity violating couplings from the branching fractions. But it becomes hard for large  $\tan \beta$ . Thus, any observation of the sever deviation from these branching fractions in the future collider may exclude scenarios for neutrino masses in the framework of mSUGRA with appropriate R-parity violation.

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